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Original Article

Evaluation of hemodynamic changes with ultrasound cardiac output monitoring during burn wound excision and skin grafting in severely burned patients: a prospective observational study

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Abstract: Objectives: To evaluate changes in hemodynamic parameters using the Ultrasound Cardiac Output Monitoring (USCOM) method during general anesthesia for burn wound excision and skin grafting surgery in patients with severe burns. Methods: This prospective observational study included 40 severe burn patients, aged 18-60 years, treated at the Intensive Care Unit (ICU) of Le Huu Trac National Burn Hospital (Hanoi, Vietnam). All patients underwent burn wound excision and skin grafting between June 2023 and March 2024. Results: The average heart rate (HR) at the study time points ranged from 116.8 to 124.3 beats/min. The differences in HR at T_1, T_2, T_3, T_5, and T_6 compared to T_0 were statistically significant ($P < 0.05$). Mean arterial pressure (MAP) at the study time points ranged from 73.8 mmHg to 95.68 mmHg. The differences in MAP at T_1, T_2, T_3, T_4, and T_5 compared to T_0 were statistically significant ($P < 0.05$). Cardiac Output (CO) and Cardiac Index (CI) values at all study time points were within normal ranges (6-7.04 l/min and 3.66-4.33 l/min/m^2, respectively). CO and CI were highest at T_0 (7.04 l/min; 4.33 l/min/m^2) and lowest at T_1 (6 l/min; 3.66 l/min/m^2). The differences in CO and CI at T_1, T_2, T_4, T_5, and T_6 compared to T0 were statistically significant ($P < 0.05$). Stroke Volume (SV) and Stroke Volume Index (SVI) values at all time points were within normal ranges (51.2-56.75 ml and 30.93-34.53 ml/m^2). The differences in SV and SVI at T_1, T_4, and T_5 compared to T_0 were statistically significant ($P < 0.05$). Systemic Vascular Resistance (SVR) and Systemic Vascular Resistance Index (SVRI) values at all time points were within normal ranges (1006.03-1240.45 d.s.cm^{-5} and 1681.98-2060.4 d.s.cm^{-5}.m^2). SVR and SVRI were highest at T_6 (1240.45 d.s.cm^{-5} and 2060.4 d.s.cm^{-5}.m^2) and lowest at T_1 (1006.03 d.s.cm^{-5} and 1681.98 d.s.cm^{-5}.m^2). The differences in SVR and SVRI at T_1 compared to T_0 were statistically significant ($P < 0.05$). Conclusion: The study demonstrated that hemodynamic parameters, including CO, CI, SV, SVI, SVR, and SVRI, remained within normal ranges throughout the anesthesia process. However, heart rate and blood pressure tended to be elevated, reflecting the hemodynamic characteristics of burn patients. This underscores the importance of close monitoring and adaptive management during anesthesia and resuscitation to ensure hemodynamic stability tailored to the characteristics of severe burn patients.

Keywords: Ultrasound Cardiac Output Monitoring (USCOM), general anesthesia, wound excision, skin grafting, burn

Introduction

Blood loss during surgery can lead to significant hemodynamic disturbances, compromising the function of vital organs such as the heart, kidneys, and brain. These disturbances can result in serious complications, including acid-base imbalance, hypothermia, coagulopathy, and, in extreme cases, death. In patients with severe burns, wound excision and skin grafting are often associated with considerable blood loss. It has been reported that for every 1% of burn necrosis area removed - including both the necrotic tissue and the autologous skin grafting area - approximately 0.9% of the patient's blood volume may be lost [1]. Therefore, meticulous hemodynamic monitoring during these procedures is essential for the early detection and prompt correction of hemodynamic instability.

In recent years, ultrasound-based cardiac output monitoring (USCOM) has emerged as a

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valuable, non-invasive tool for hemodynamic assessment. Numerous studies have demonstrated that USCOM provides highly accurate measurements compared to invasive techniques, such as pulmonary artery catheterization (PAC), Pulse index Contour Cardiac Output (PiCCO), and transthoracic echocardiography [2-7]. Moreover, USCOM has proven effective in establishing baseline hemodynamic parameters across various physiological states, including the monitoring of healthy high-altitude residents [8]. While USCOM has been successfully applied in fields such as cardiovascular surgery [9], liver transplantation [10], and intensive care units (ICUs) [11], its use in wound excision and skin grafting for severe burn patients remains limited. Therefore, this study aimed to evaluate changes in key hemodynamic parameters using the USCOM method during anesthesia for wound excision and skin grafting in patients with severe burns.

Methods

Subjects and study design

This prospective observational study evaluated hemodynamic parameters in 40 severely burned patients who underwent burn wound excision and skin grafting at Le Huu Trac National Burn Hospital, Vietnam, between June 2023 and March 2024. Inclusion criteria were: age 18-60 years, burn area involving 30-60% of the total body surface area, and an indication for burn necrosis excision covering 5-15% of the body surface. Eligible patients were classified as American Society of Anesthesiologists (ASA) physical status II or III. Exclusion criteria included concurrent trauma or pre-existing cardiovascular diseases, such as valvular heart disease, severe heart failure (New York Heart Association [NYHA] class III or IV), or arrhythmias. The study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Medications and equipment

Medications included midazolam, ketamine, fentanyl (Rotexmedica, Germany), and propofol (Fresenius Kabi, Austria). Supportive resuscitation drugs and infusion fluids were also administered. Equipment included a USCOM version 2 device (Uscom, Australia, 2009) with a 2.2 MHz Doppler probe (**Figure 1**) and a Nihon Kohden Life Scope Monitor (Japan) for monitoring heart rate, ECG, invasive arterial blood pressure, respiratory rate, and SpO_2.

Anesthesia procedure

Patients underwent a preoperative anesthesia assessment one day prior to surgery and were instructed to follow preoperative fasting guidelines. In the operating room, after establishing monitoring, Ringer's lactate solution was infused at a rate of 10 ml/kg of body weight. Anesthesia was induced with midazolam 0.05 mg/kg IV as premedication, followed by ketamine 1 mg/kg, fentanyl 3 μg/kg, and propofol 3 mg/kg, all administered IV. A laryngeal mask airway was inserted after the patient lost consciousness and achieved sufficient muscle relaxation. During maintenance, volume-controlled ventilation (VCV) was employed with a tidal volume of 8 ml/kg ideal body weight, a respiratory rate of 14-16 breaths/min, and an inspiratory-expiratory ratio of 1:2, maintaining $EtCO_2$ between 30 and 40 mmHg. Propofol infusion was sustained at 1 mg/kg/h, with adjustments of ± 0.2 mg/kg/h as needed, and additional fentanyl (1-2 μg/kg) was administered based on PRST scores (systolic blood pressure, heart rate, sweating, and tear production). Vital signs were recorded every 5 minutes throughout the procedure.

Postoperative care: In the recovery room, the laryngeal mask airway was removed once the patient met the criteria for consciousness, hemodynamic stability, and adequate respiratory function. The assessment was conducted as follows:

Consciousness: The patient's ability to respond to verbal commands was evaluated, consistent with standard post-anesthesia monitoring practices.

Hemodynamic stability: Heart rate and blood pressure were continuously monitored to ensure cardiovascular stability, with cardiac output measured using the USCOM device if necessary.

Respiratory function: Adequate respiratory function was confirmed by monitoring respiratory rate, oxygen saturation (SpO_2), and the absence of respiratory distress.

Figure 1. Uscom machine (Uscom, Australia, 2009) and the method to measure. A: Uscom version 2 machine; B and C: Probe Placement: aortic outflow (suprasternal notch).

Table 1. The Modified Adrete scoring system

Assessment items	Condition	Grade
Activity, able to move, voluntarily or on command	4 extremities	2
	2 extremities	1
	No	0
Breathing	Able to breathe deeply and cough freely	2
	Dyspnea, shallow or limited breathing	1
	Apnea	0
Consciousness	Fully awake	2
	Arousable on calling	1
	Unresponsive	0
Circulation (BP)	± 20% of pre-anesthesia level	2
	± 20% to 49% of pre-anesthesia level	1
	± 50% of pre-anesthesia level	0
SpO_2	Maintains SpO_2 > 92% in ambient air	2
	Maintain SpO_2 > 90% with O_2	1
	Maintain SpO_2 < 90% with O_2	0

Patients were transferred to the clinical ward upon achieving a modified Aldrete score of ≥ 9 (**Table 1**).

Recorded parameters and study time points

The collected data included patient demographics (age, gender, height, weight), burn wound excision area, and skin graft area. The dosages of administered medications (midazolam, ketamine, propofol, fentanyl), the volume of infused fluids, and the blood products used during surgery were also recorded. Changes in heart rate (HR) and arterial blood pressure during the procedure were documented, along with hemodynamic parameters measured by the USCOM device, including cardiac output (CO), cardiac index (CI), systemic vascular resistance (SVR), systemic vascular resistance index (SVRI), stroke volume (SV), and stroke volume index (SVI).

Hemodynamic parameters were recorded at seven specific time points: T_0 (immediately after premedication), T_1 (immediately after induction of anesthesia), T_2 (prior to burn wound excision), T_3 (at the start of burn wound excision), T_4 (end of burn wound excision), T_5 (at the end of skin grafting), and T_6 (upon patient awakening).

Data analysis

Data are presented as means with standard deviation (SD) and range for continuous variables, or as counts and percentages for categorical variables. Statistical analysis was performed using SPSS Statistics, version 22.0 (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test assessed data normality, with parametric tests (paired-sample t-tests) for normally distributed data and the Wilcoxon signed-rank test for non-normally distributed data. Hemodynamic parameters were compared between baseline (T_0) and subsequent time points (T_1-T_6), accounting for repeated measurements. A *p*-value of < 0.05 was considered statistically significant.

Ethical considerations

The research proposal was approved by the Research Proposal Review Committee and received ethical approval from the Ethics Committee in Biomedical Research of Vietnam Military Medical University (certification number 42/2023/CNChT-HĐĐĐ, June 16, 2023). The study followed decision number 2820/QĐ-HVQY (July 17, 2023) from the university. It complies with the Declaration of Helsinki, published by the World Medical Association (WMA). Patient data was securely stored, and written consent was obtained from patients and their families prior to the study.

Results

Patients' demographics

Table 2 presents the general characteristics of the patients. The mean age was 37.7 ± 13.41 years, with a male predominance (82.5%). The average areas of necrotic excision and skin

Table 2. Patients' characteristics

Parameters	Min-Max	$\bar{X} \pm SD$
Age (year)	18-59	37.7 ± 13.41
Sex (n, %)	Male 33 (82.5%) Female 7 (17.5%)	
Weight (kg)	45-78	60.83 ± 8.57
Height (cm)	155-180	165.15 ± 6.84
Necrotic excision area (%)	5-15	9.53 ± 3.21
Skin grafting area (%)	5-15	9.6 ± 3.16
Surgery duration (min)	30-90	56.75 ± 12.48
Anesthesia duration (min)	55-115	81.32 ± 14.91
Midazolam (mg)	2.25-4	2.96 ± 0.46
Ketamin (mg)	45-80	60.10 ± 9.10
Propofol (mg)	350-1000	615.25 ± 146.04
Fentanyl (µg)	150-500	335.5 ± 71.96
Volume of crystalloid fluids used during surgery (ml)	500-1000	693.75 ± 208.22
Volume of blood used during surgery (ml)	0-500	328.75 ± 84.64

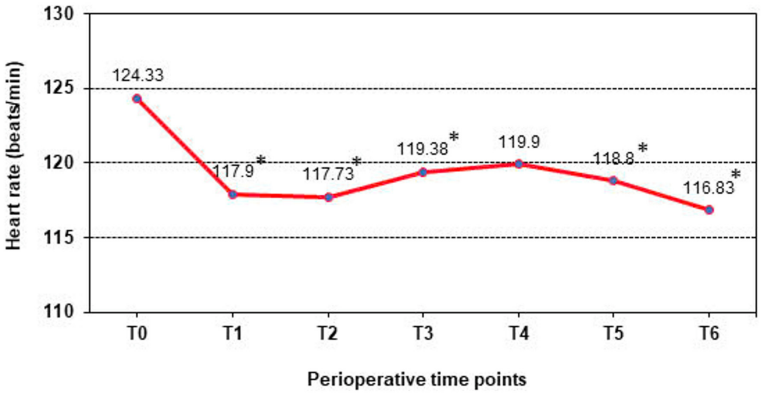

Figure 2. Heart rate at perioperative time points. *P < 0.05 when comparing time points with T_0 (paired-sample T-test).

grafting were nearly identical, measuring 9.53 ± 3.21% and 9.6 ± 3.16% of the total body surface area (TBSA), respectively. The mean duration of surgery was 56.75 ± 12.48 minutes, and the average duration of anesthesia was 81.32 ± 14.91 minutes. The average doses of midazolam, ketamine, propofol, and fentanyl administered were 2.96 ± 0.46 mg, 60.10 ± 9.10 mg, 615.25 ± 146.04 mg, and 335.5 ± 71.96 µg, respectively. The mean volumes of crystalloid fluids and blood used during surgery were 693.75 ± 208.22 ml and 328.75 ± 84.64 ml, respectively.

Changes in hemodynamic parameters during surger

HR: The average heart rate across the study time points ranged from 116.83 to 124.33 beats per minute. Significant differences in heart rate were observed at T_1, T_2, T_3, T_5, and T_6 compared to T_0 ($P < 0.05$; **Figure 2**).

MAP: MAP measurements ranged from 73.8 mmHg to 95.68 mmHg throughout the surgery. Statistically significant changes in MAP were observed at T_1, T_2, T_3, T_4, and T_5 compared to T_0 ($P < 0.05$; **Figure 3**).

CO and CI: CO and CI remained within normal limits at all study time points, with CO ranging from 2.51 to 7.77 l/min and CI from 1.49 to 4.69 l/min/m^2. The highest values were observed at T_0 (7.04 l/min and 4.33 l/min/m^2), while the lowest were at T_1 (6 l/min and 3.66 l/min/m^2). Significant decreases were observed in CO and CI at T_1, T_2, T_4, T_5, and T_6 compared to T_0 ($P < 0.05$; **Figure 4**).

SV and SVI: SV and SVI values also remained within normal ranges, with SV ranging from 39.1 to 98.5 ml and SVI from 23.2 to 56.6 ml/m^2. Statistically significant changes in SV and SVI were observed at T_1, T_4, and T_5 compared to T_0 ($P < 0.05$; **Figure 5**).

SVR and SVRI: SVR and SVRI values fluctuated within their normal ranges during surgery, with SVR ranging from 906 to 2950 d.s.cm^{-5} and

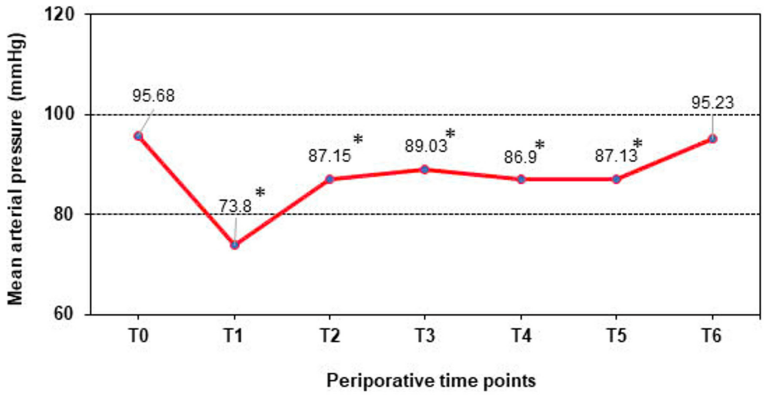

Figure 3. Mean arterial pressure at perioperative time points. *P < 0.05 when comparing time points with T_0 (paired-sample T-test).

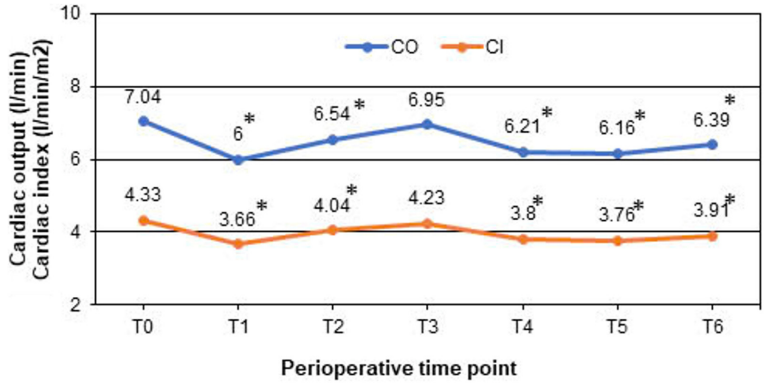

Figure 4. Cardiac output and cardiac index at perioperative time points. *P < 0.05 when comparing time points with T_0 (paired-sample T-test); CO: cardiac output; CI: cardiac index.

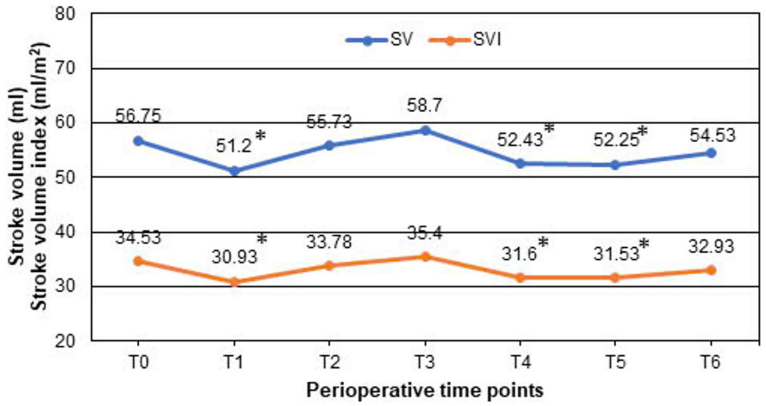

Figure 5. Stroke volume and stroke volume index at perioperative time points. *P < 0.05 when comparing time points with T_0 (paired-sample T-test); SV: Stroke volume, SVI: stroke volume index.

SVRI from 1499 to 5073 d.s.cm^{-5}.m^2. The highest values were recorded at T_6 (1240.45 d.s.cm^{-5} and 2060.4 d.s.cm^{-5}.m^2), while the lowest at T_1 (1006.03 d.s.cm^{-5} and 1681.98 d.s.cm^{-5}.m^2). Significant differences were observed between T_0 and T_1 were observed (P < 0.05) (**Figure 6**).

Discussion

Changes in heart rate and mean arterial pressure

Heart rate (HR) is a critical parameter in hemodynamic monitoring, as it directly influences cardiac output (CO), which is essential for maintaining organ perfusion. HR may increase when anesthesia depth is insufficient or when the patient experiences pain, while a decreased HR is often linked to deeper anesthesia or the effects of medications such as fentanyl or propofol. In patients with severe burns, HR can significantly increase due to elevated catecholamine levels, a condition that may persist for up to two years following the burn injury [12].

In this study, HR ranged from 116.83 to 124.33 beats per minute during burn wound excision and skin grafting (**Figure 2**). Statistically significant differences in HR were observed at T_1, T_2, T_3, T_5, and T_6 compared to T_0 (P < 0.05), indicating notable hemodynamic changes during the procedure. The decrease in HR at T_1 and T_2 may be attributed to the effects of propofol during anesthesia induction and maintenance. At T_2, adrenaline was administered to limit blood loss, which likely contributed to the subsequent increase in HR. Although HR fluctuated at different time points, the average HR remained

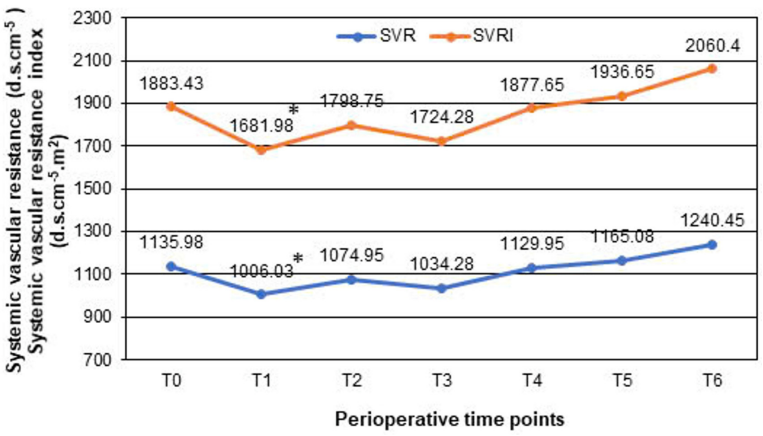

Figure 6. Systemic vascular resistance and systemic vascular resistance index at perioperative time points. *P < 0.05 when comparing time points with T_0 (paired-sample T-test); SVR: Systemic vascular resistance, SVRI: systemic vascular resistance index.

within a safe range throughout the surgery. These findings suggest that, despite the influence of medications and the surgical procedure, HR was effectively controlled to maintain adequate cardiac output, ensuring proper organ perfusion during the surgery.

Maintaining stable cardiovascular function during surgery and anesthesia is critical for ensuring adequate blood and oxygen delivery to vital organs. Arterial blood pressure serves as a key indicator of the heart's pumping efficiency and vascular resistance, as well as a determinant of tissue perfusion pressure, which governs blood flow to various body tissues [13], It is widely regarded as a reliable marker of tissue perfusion adequacy [14]. According to Michael Walsh, an intraoperative mean arterial pressure (MAP) below 55 mmHg is associated with a heightened risk of acute kidney and myocardial injury [15]. Furthermore, intraoperative hypotension correlates with increased risks of myocardial injury, acute kidney injury, and mortality, with the risks intensifying as MAP drops below 60-70 mmHg [16, 17].

The results presented in **Figure 3** show that MAP ranged from 73.8 to 95.68 mmHg. Statistically significant differences in MAP were observed at T_1, T_2, T_3, T_4, and T_5 when compared to T_0 ($P < 0.05$). The reduction in MAP at T_1 is likely attributable to the hypotensive effects of propofol, whereas the increase at T_2 reflects the action of administered adrenaline. Despite fluctuations during the procedure, MAP remained consistently above 70 mmHg, ensuring stable blood pressure and sufficient perfusion to the organs throughout the surgery.

Changes in several hemodynamic parameters measured by USCOM

Changes in CO and CI: Cardiac function is represented by CO, defined as the volume of blood the heart pumps per minute on average. CO results from the interaction of four factors: preload, myocardial contractility, afterload, and heart rate. It is calculated as the product of stroke volume and heart rate [18]. CO is a vital physiological indicator that reflects the body's overall metabolic activity and demonstrates its ability to adapt to increased workload by elevating both heart rate and stroke volume [19].

The CI is the Cardiac Output standardized to body surface area, allowing adjustments based on a patient's size [20]. CI is an important clinical parameter for evaluating cardiac function, particularly in patients with severe heart disease or during anesthesia [19]. Monitoring CI offers more precise insight into cardiac performance and plays a crucial role in assessing heart failure as well as in pharmacological research [19, 20].

In this study, the average age of the patients was 37.7 ± 13.41 years (18-59) (**Table 2**). In this age group, CO values ranged from 2.51 to 7.77 l/min, while CI values ranged from 1.49 to 4.69 l/min/m^2 [21]. The results presented in **Figure 4** indicate that CO and CI values at the study time points remain within normal ranges. Overall, CO and CI showed a tendency to decrease after induction, with statistically significant differences at T_1, T_2, T_3, T_4, T_5, and T_6 compared to T_0 ($P < 0.05$).

CO and CI showed a significant decrease after induction at T_1, T_2, T_3, T_4, T_5, and T_6 compared to T_0 ($P < 0.05$), reflecting the effects of propofol on reducing myocardial contractility and systemic vascular resistance [22]. At T_3, CO and CI increase again due to the inotropic and tachy-

cardic effects of adrenaline [23], compensating for the depressant effects of propofol. From T_3 to T_5, the decline in CO and CI continued, primarily due to the prolonged effects of propofol and the gradual decrease in adrenaline's effects. At T_6, after discontinuing propofol, CO and CI began to recover, indicating hemodynamic restoration. Despite fluctuations, CO and CI remained within normal ranges, ensuring effective organ perfusion throughout the surgery.

Van Lelyveld-Hass et al. (2008) used USCOM to investigate CO and CI in mechanically ventilated ICU patients, reporting an average CO value of 6.06 ± 1.9 l/min and an average CI value of 2.7 ± 0.7 l/min/m^2 [11]. Bai-Chuan Su et al. (2008) used USCOM to measure cardiac output in liver transplant patients, reporting an average CO value of 8.35 ± 2.35 l/min [6]. Karsten Knoblock et al. (2005) used USCOM to assess cardiac output in cardiac surgery patients, reporting an average CO value of 5.15 ± 1.98 l/min [5]. Sophia Hoster et al. (2012) used USCOM to evaluate cardiac output in patients with sepsis, reporting an average CO value of 6.5 ± 2.18 l/min [3].

Changes in SV and SVI: SV refers the volume of blood ejected from the left ventricle of the heart with each heartbeat and plays a crucial role in determining CO, as CO is the product of SV and HR [24]. SV is increasingly recognized as a key hemodynamic variable, replacing traditional parameters in the assessment of cardiac function and organ perfusion due to its reduced susceptibility to compensatory mechanisms [24]. The SVI is calculated by dividing SV by body surface area, allowing for the normalization of SV for comparison among patients with varying body sizes.

Both SV and SVI are crucial for assessing preload and myocardial contractility. The values of SV and SVI are influenced by three main factors: preload, myocardial contractility, and afterload. Low SV and SVI levels may indicate reduced preload (fluid deficit), impaired myocardial contractility, or increased afterload. Conversely, elevated SV and SVI levels may result from fluid overload, enhanced myocardial contractility, or decreased afterload. Additionally, these values can also be heightened by factors such as pain or anxiety.

In this study, the average age of patients was 37.7 ± 13.41 years (18-59). In this age group, SV values ranged from 39.1 to 98.5 ml, and SVI values ranged from 23.2 to 56.6 ml/m^2 [21]. As shown in **Figure 5**, SV and SVI values at all time points remained within normal ranges. Statistically significant differences in SV and SVI were observed at T_1, T_4, and T_5 compared to T_0 ($P < 0.05$). Liu Zhang et al used USCOM to evaluate hemodynamic parameters in critically ill patients, reporting an average SV of 61.9 ± 19.7 ml/m^2 [25].

During surgery, CO and CI are directly influenced by changes in SV and SVI, which are affected by preload, myocardial contractility, and afterload. A reduction in preload, such as that caused by blood loss during surgery, can lead to a decrease in SV if not promptly compensated by fluid or blood transfusion. When SV decreases, CO and CI also decline, potentially impairing organ perfusion. Myocardial contractility, a crucial determinant of SV, can be influenced by anesthetics like propofol, potentially resulting in decreased CO even when SV remains stable.

Afterload, as reflected by SVR, also impacts CO and CI: when SVR is elevated due to peripheral vasoconstriction, the heart must increase its contractility to overcome the resistance, thereby increasing cardiac workload. Conversely, a reduction in SVR due to medication or vasodilation can lead to an increase in CO, particularly when accompanied by a compensatory increase in SV. These factors interact dynamically and require flexible adjustments to maintain stable hemodynamics, especially in complex surgical cases such as burn wound excision and skin grafting in patients with severe burns.

Changes in SVR and SVRI: SVR and SVRI are essential parameters for assessing afterload. SVR, also referred to as total peripheral vascular resistance, depends on three main factors: blood vessel length, blood vessel diameter, and blood viscosity. SVR plays a crucial role in the formation and regulation of blood pressure, as expressed by the formula: MAP = CO × SVR [26]. The normal range for SVR is typically between 906 and 2950 d.s.cm^{-5} [21]. SVRI measures the resistance of the peripheral vascular system to blood flow, adjusted for each patient's body size. Since SVRI is adjusted for body surface area (BSA), it allows for more accurate comparisons between patients with varying body sizes. The relationship is described

by the formula SVRI = SVR × BSA [21]. The normal range for SVRI is 1499-5073 d.s.cm^{-5}.m^2 [21].

According to the results in **Figure 6**, SVR and SVRI values at all time points remained within normal ranges, with the lowest levels recorded at T_1 (1006.03 d.s.cm^{-5} and 1681.98 d.s.cm^{-5}, respectively) and the highest levels recorded at T_6 (1240.45 d.s.cm^{-5} and 2060.45 d.s.cm^{-5}, respectively). An increase in SVR can impose a greater workload on the heart and reduce CO if the heart is unable to compensate for the increased resistance. Conversely, a decrease in SVR due to vasodilation can facilitate blood flow but may lead to hypotension if not properly managed.

Although our study offers several novel insights and contributions, it has certain limitations, including a small sample size, its cross-sectional and single-center design, and the absence of a control group to compare the hemodynamics obtained using the USCOM machine. We strongly recommend further research to establish scientific evidence applicable to the treatment and care of patients with severe burns.

Overall, this study demonstrates that hemodynamic parameters, including CO, CI, SV, SVI, SVR, and SVRI, remained within normal ranges during burn wound excision and skin grafting procedures, despite certain fluctuations from baseline. These findings underscore the importance of vigilant hemodynamic monitoring to maintain stable perfusion, reduce complications, and enhance patient recovery. Furthermore, our results highlight the utility of USCOM as a reliable and non-invasive tool for managing complex surgical cases, supporting clinical decision-making in severe burn patients.

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Disclosure of conflict of interest

None.

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